REVIEW

Sports-related acute and chronic avulsion injuries in children and adolescents with special emphasis on tennis

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Acute and chronic sports-related muscle and tendon injuries are not infrequent in youngsters. In particular, the physis is prone to trauma as it constitutes the weakest part of the immature skeleton. The type of sports activity determines the location of the lesion. Most commonly, apophyses of the hip and pelvis are subject to avulsion. The purpose of this paper is to give a short overview of the pathogenesis, location, prevalence and imaging characteristics of acute and chronic avulsion injuries in the immature skeleton, with special emphasis on tennis-related injuries. Tennis-related injuries particularly involve apophyses of the ischial tuberosity, the anterior inferior or superior iliac spine and the iliac crest.

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Sports-related muscle and tendon injuries are frequent in adults and in youngsters. As sports activities have gained popularity in adolescents and children, this has led to more sports-related injuries.[1] The kind of sports activity and the mechanism of trauma determine the nature of the lesion.[1 2] In continental Europe, soccer is the most frequent sports discipline resulting in injuries of the young patient.[2] However, as tennis becomes more popular in youth clubs, there is an increasing incidence of similar sports injuries in young tennis players. Tennis requires repeated, explosive motion that imposes a high load of strain on the skeleton. Unlike many other sports, tennis also requires an exceptional range of motion (ROM) in all directions, thus involving a diverse range of muscles and tendons. Moreover, especially in the case of young elite players, adult training schemes are sometimes applied, without considerations for the vulnerability of the immature skeleton. The physical characteristics of the young tennis player mean that unique demands are placed on the developing athlete that can, in turn be associated with different types and patterns of injury. Anatomically, lower extremity injuries are twice as common as those to the upper extremity or spine.[3] Most commonly apophyses of hip and pelvis are subject to avulsion in youngsters.[2] Such lesions can be either acute or chronic. This article reviews the basic anatomy and physiology of muscles and the imaging characteristics of acute and chronic muscle injuries in the immature skeleton.

BASIC PHYSIOLOGY AND ANATOMY

Muscle activation generates force within the muscle. When the resisting load is less than the force generated by the muscle, the contraction is concentric and the muscle shortens. By contrast, when the resisting load exceeds the force generated by the muscle, the contraction is eccentric, resulting in lengthening of the muscle.[4]

Muscles often contract eccentrically to absorb kinetic energy and protect joints. However, eccentric muscle activation can produce more force or tension within the muscle than when it is activated concentrically, making it more susceptible to rupture or tearing.[4 5]

The anatomy of the muscle–tendon–bone complex is different in the adult compared to children and adolescents. In adults, in whom apophyseal ossification is complete, indirect muscle injuries tend to occur near the myotendinous junction, but the weakest link in the immature skeleton is the physis.[1 2 6–9] In children and adolescents ligaments and tendons can withstand more force than bones, but the growth plates at the apophyses are more prone to trauma, especially to avulsion.[1] In particular, the apophyses of the pelvis and hip are common sites of acute avulsions, as they tend to appear and fuse later than many other epiphyseal centres.[3 4 10] Knowledge of the age of the patient and familiarity of the major tendinous insertions contributing to these avulsions is imperative in achieving early diagnosis of avulsive injuries.

As different sports activities involve the use of different muscles, the sites that are prone to avulsive injuries depend on the kind of sports practiced (table 1).[1 2]

In tennis, repeated, sudden and very explosive motion in many directions, for instance during service, while returning the ball, or during take-off towards the ball can cause apophyseal lesions of the immature skeleton.[11]

Although the nature of the sport is the most important factor, determining the location of the injury, there can be some overlap and similar lesions can be encountered in different sports disciplines.

Moreover, imaging features are not specific for the causative sport.

ACUTE AVULSIVE INJURIES

As the physis is the weakest part of the immature skeleton, it is vulnerable to both direct trauma and

Abbreviations: AIIS, anterior inferior iliac spine; ASIS, anterior superior iliac spine; IC, iliac crest; IT, ischial tuberosity; LT, lesser trochanter; ROM, range of motion; SCPS, superior corner of pubic symphysis

Table 1 Most frequent sites of avulsion fractures, their corresponding muscle insertion and the most frequent athletic activities responsible for these lesions

Location (decreasing order of frequency)	Muscle insertion	Most frequent sports activities
IT	Hamstrings	Gymnastics, soccer, fencing, tennis, running
AIIS	Rectus femoris	Soccer, athletics, tennis
ASIS	Sartorius	Soccer, athletics, gymnastics
SCPS	Rectus abdominis	Soccer, fencing
IC	Abdominal muscles	Soccer, gymnastics, tennis
LT	Iliopsoas	Athletics

IT, ischial tuberosity; AIIS, anterior inferior iliac spine, ASIS, anterior superior iliac spine; SCPS, superior corner of pubic symphysis; IC, iliac crest; LT, lesser trochanter

avulsion injuries.[9] Avulsion injuries can occur anywhere in the immature skeleton,[12] but usually occur at the pelvis and are related to the time of appearance of ossification of the apophyses and their fusion to the corresponding pelvic tuberosities (table 1).[2 13 14]

In tennis, most avulsion injuries occur in the lower extremities, followed by the upper extremities and then the trunk.[3 10 15] Avulsion fractures outside the pelvis though are rare and not specifically correlated with tennis.[13]

The age of presentation of the apophyseal avulsion fracture is between puberty and 25 years at which time the apophyses have fused.[3 4] The mean age of occurrence is 13.8 years.[2]

The athlete experiences sudden shooting pain referred to the involved tuberosity, followed by restricted active motion and weakness.[1 9] Clinical examination reveals loss of muscular function, swelling and local tenderness, evoked during movement of the affected limb, or during contraction of the abdominal wall muscles by twisting and flexing the abdomen, in the case of tennis.[2]

Avulsions due to direct trauma are certainly possible, but the pathogenesis usually consists of an indirect trauma, due to the tearing action exerted by a sudden, violent concentric or eccentric muscle contraction.[1 2 8 16] Table 1 summarises the most frequent sports activities responsible for each specific site of involvement: the highest number of lesions are found in soccer players, gymnasts and athletics, but other sports provoking avulsive injuries are tennis, fencing, handball, pentathlon, basketball and so on.[2]

Injuries to the IT are generally related to sudden and excessive passive lengthening of the hamstring muscles for instance during floor exercises in gymnasts. Tennis players have been shown to have a smaller ROM in both hamstrings than in other athletes, while serving.[17] This poor hamstrings ROM can be explained by the need for tennis players to be in the typical ‘‘low ready position’’. This is the most efficient starting position for explosive movement, because of the lowered centre of the mass, but it does require the athlete to have the hamstrings in a shortened, contracted position for long periods.[18] However, during the explosive motion towards the ball, excessive passive lengthening of the hamstrings can cause sudden avulsion of the ischial tuberosity.

Injuries to the ASIS and AIIS mostly occur in soccer players due to an excessive upwards movement of the leg in ‘‘kicking the air’’ or a powerful shot at the goal with maximum flexion of the hip and extension of the knee.[2] In tennis, these lesions can occur due to a relative overpull of the sartorius or rectus femoris muscle respectively during jumping or running or a sudden acceleration motion.

Lesions of the IC are rather uncommon and in the acute form mostly associated with abrupt changes of direction.[13] During power serves and ground strokes (especially with two-handed play) a tennis player violently rotates the trunk in order to generate greater force on the ball, thus generating a large amount of tension on the iliac crest through the abdominal muscles.[3 11] The order of maximum angular velocities during pelvis rotation in order to produce high-velocity serves can be

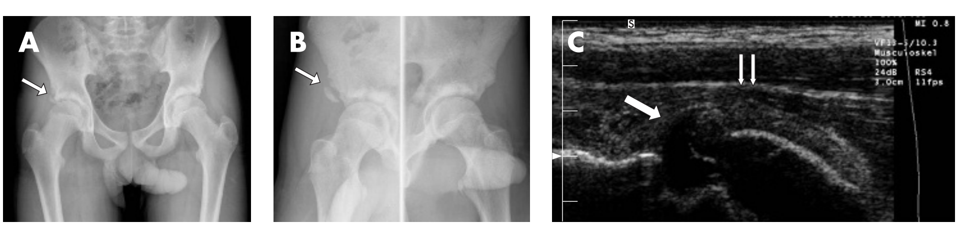

Figure 1 Acute avulsion fracture of the right anterior inferior iliac spine in a 14-year-old male tennis player with acute pain at the right hip. (A) Radiograph of the pelvis showing separation of the right AIIS (arrow) compared to the normal left side. (B) Spot view of the right and left hip. (C) Ultrasound confirms the avulsed fragment (arrow), attached to the tendon of the rectus femoris muscle (double arrow).

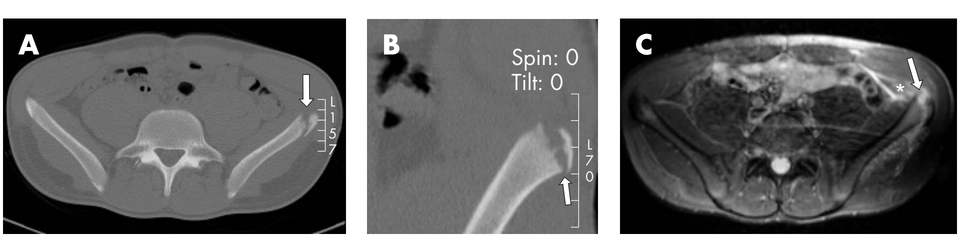

Figure 2 Avulsion of the iliac crest in a 17-year-old tennis player. (A) Axial CT at the level of the iliac crest. Note the separation of the left iliac crest from the underlying iliac bone (arrow). (B) Coronal reformatted CT at the level of the left iliac crest. Note the separation of the left iliac crest from the underlying iliac bone (arrow). (C) Axial fat suppressed T2-weighted MR image demonstrates the presence of a high signal intensity cleft between the avulsed apophysis and the iliac bone (arrow). Note also high signal intensity oedema within the adjacent abdominal wall muscles (asterisk).

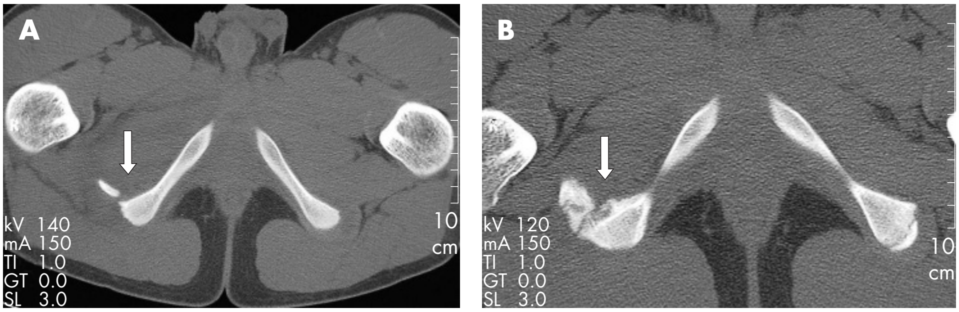

Figure 3 Pseudotumorous mass due to extensive callus formation at the ischial tuberosity. (A) Axial CT scan at the time of the trauma showing a displaced right ischial apophysis (arrow). (B) Axial CT scan 5 months after the initial trauma, demonstrating extensive callus formation mimicking a tumour (arrow).

up to 440°/s.[19] Injuries of the iliac crest in tennis are mostly due to this sudden contraction of the abdominal wall muscles.

Plain radiography is usually diagnostic, supplemented by oblique or axial projections, and can show radiological sequelae of multiple locations in about a third of patients.[2 4] Comparison with the contralateral side is important to distinguish a true avulsion fracture from the unfused apophysis.[20] Other imaging modalities, such as ultrasound, CT and MRI are usually not required. Conventional radiography will thus show a displaced fracture fragment that is noted at the origin or insertion of a muscle or tendon during the acute phase (fig 1A,B).[1 9] However, plain radiographs can be interpreted as negative in children, when an apophyseal avulsion is non-displaced or when the apophysis is unossified. In such cases, ultrasound (fig 1C), CT (fig 2A,B) and MRI (fig 2C) might prove helpful.[21]

In a study, performed by Lazovic *et al*, 243 young athletes, with clinical suspicion for apophyseal avulsion fractures were examined by means of radiography and ultrasound.[22] In 80 cases the diagnosis was confirmed by radiographs, and in 97 cases by ultrasound, confirming the higher sensitivity for ultrasound in young children.

Minimal displacement of the avulsed ossified apophysis is more readily detected by CT, and CT should be performed in case of a high clinical index of suspicion, when standard radiographs are negative.

MRI will show haematoma and periosteal stripping at the tendinous attachment sites. Waviness and retraction of the torn end of the tendon along with a fragment of bone or cartilage can be seen.[20] By contrast, cortical fracture fragments that do not contain marrow can be easily missed on MRI.

MRI is advocated to evaluate the degree of tendon retraction, which can influence the prognosis of the lesion. This is particularly useful for hamstrings lesions, as these are prone to severe tendon retraction. Indeed, if the tendon is retracted more than 2 cm, this can result in abnormal healing and extended disability.

In the healing phase, plain radiographs, CT and MRI can show excessive callus with hypertrophy and deformity of the adherent cortex at any of the fracture sites (figs 3A,B and 4A,B). If a clear history of trauma is absent, this can easily be misinterpreted as an osteosarcoma or exostosis.[1 4 7 21] Such patients can present to the tumour clinic rather than to the sports clinic.[23] To exclude a true tumorous mass, cross-sectional imaging is then often performed. Exuberant callus formation at the ischial tuberosity can cause impingement on the sciatic nerve. In these cases CT might be helpful in management planning, if surgical resection of painful hypertrophic callus is considered.[13]

MRI can also be useful in the healing phase to distinguish true non-union of an avulsed fragment versus fibroosseous union of the avulsed fragment. In case of non-union, MRI will show a persistent high signal intensity on T2-weighted images or STIR images between the displaced apophyseal fragment and the underlying bone.

Fibro-osseous healing can be documented by focal hypointense bridging of the apophyseal growth plate on gradient echo imaging.[24] If the bridge is purely fibrous, this might not be detectable by conventional radiography or CT. Abundant callus formation, which can be painful, can cause an intense contrast enhancement at the apophyseal growth plate.[9]

MR imaging is also an excellent tool for follow-up of acute lesions to evaluate muscle atrophy and fatty infiltration.[25]

Acute avulsive injuries are best treated conservatively with bed rest and restricted activity. The location of the injury determines the time to return to full athletic performance, taking over 6–12 weeks following IT avulsion, versus a shorter recovery time of 5–6 weeks for avulsion of the ASIS and AIIS.[20]

If, however, a recent apophyseal avulsion fragment is displaced more than 2 cm, surgery could be considered.[21] In case of old avulsions, surgical excision of a malunited or hypertrophic fragment can provide relief of pain in some patients.[26]

SUBACUTE AND CHRONIC AVULSIVE INJURIES

Repetitive overuse can also lead to subacute and chronic avulsive or insertional injuries in some adolescent sports players, such as youth soccer players and runners, but also in tennis players.[7]

These lesions present more insidiously, with pain localised mostly at the groin but without a clear history of trauma. Typical examples occur at the proximal attachment of the gracilis and adductor muscles at the symphysis pubis and the inferior pubic ramus (gracilis-adductor syndrome or proximal chronic avulsive adductor insertion syndrome).[27]

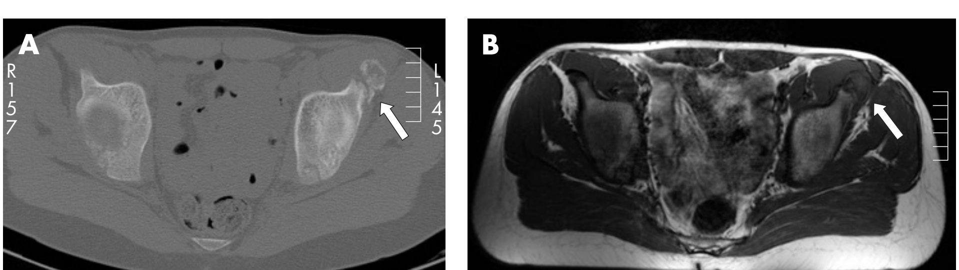

Figure 4 Old apophyseal avulsion fracture at the AIIS in a 15-year-old male tennis player. (A) Axial CT demonstrates a bony mass (arrow) at the insertion of the rectus femoris muscle at the left AIIS, due to unremodelled callus formation. In the absence of history of previous sports trauma, this can mimic a malignant bone tumour. (B) Axial T1-weighted MR image confirming a pseudotumorous lesion at the insertion of the rectus femoris muscle at the left AIIS (arrow).

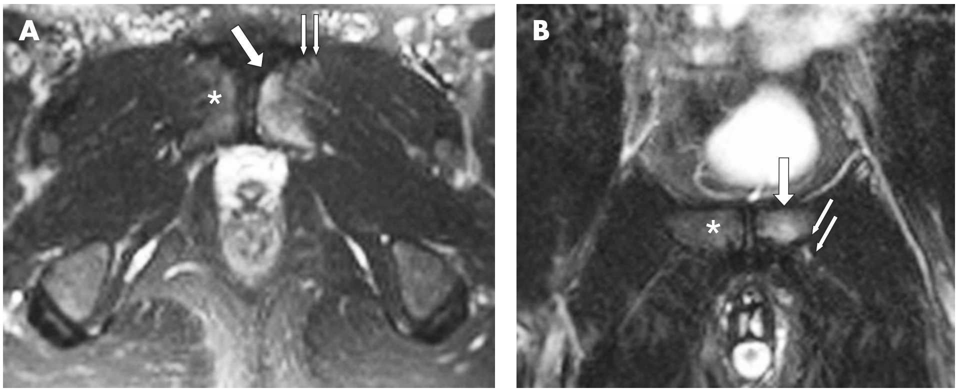

Figure 5 Gracilis-adductor syndrome in a 15-year-old male tennis player. (A) Axial fat suppressed T2-weighted MR image. (B) Coronal fat suppressed T2-weighted MR image. Note bone marrow oedema at the insertion of the gracilis and adductor tendon at the inferomedial part of the left pubic bone (arrow). Note also soft tissue oedema within the left proximal adductors (double arrow). Minor similar bone marrow oedema is also present on the right side (asterisk).

Radiographically, areas of bony rarefaction, or even significant lysis can be seen, resembling a more aggressive lesion, such as an infectious or neoplastic process.[4 16 27 28] In the healing phase, there can be a mixture of bony lysis and sclerosis.[28 29] Occasionally multiple avulsions can be seen in different stages of healing in the same patient.[1 9]

MRI and scintigraphy are more sensitive as diagnostic imaging tools in early stages. Scintigraphy shows a high tracer uptake at the inferior side of the inferior pubic ramus. In the initial stages, MRI will demonstrate parasymphyseal bone marrow (fig 5A,B) and peripubic soft tissue oedema on fluid sensitive sequences (fat-suppressed T2-weighted images and STIR images).[20 23] Fatty replacement and sclerosis can be seen in subacute and chronic stages. MR imaging can also be used for precise identification of the specific musculotendinous unit involved.[20]

Another chronic insertional injury, occurring at the distal attachment of the adductor brevis muscle at the medial middle third of the femoral diaphysis is referred to as the distal chronic avulsive adductor insertion syndrome, better known as thigh splints.[30] Radiography is rarely diagnostic in the early phase, but can reveal limited periosteal bone apposition at the medial proximal third of the femur in advanced cases.[29] On scintigraphy, a focal linear increased tracer uptake is seen at this site, whereas MRI reveals a combination of soft tissue oedema at the periosteal site and bone marrow oedema within the adjacent marrow cavity of the femur.[30]

Most patients with chronic avulsive injuries will respond to conservative treatment and decreased athletic activity.

What is already known on this topic

- Sports-related acute and chronic apophyseal avulsion injuries of the pelvis and hip are common in children and adolescents.
- Conventional radiography is usually diagnostic, and additional imaging techniques such as ultrasound, CT and MRI are only required in specific cases.
- Chronic avulsion injuries can simulate a neoplastic or infectious process.

What this study adds

- The current manuscript focuses particularly on the imaging features of these lesions in youth tennis players.
- The merits of each imaging technique used for diagnosis are summarised.

CONCLUSIONS

Muscle and tendon injuries in skeletally immature adolescent athletes engaged in high level sports activities are not rare. Due to the increasing popularity of tennis in youth players, more such traumatic lesions will be encountered in youngsters.

Acute trauma in this age group usually results in an apophyseal avulsion fracture. The diagnosis, suggested by physical findings and symptoms, is usually confirmed by plain radiographs.

Chronic avulsive injuries occur more insidiously and are often neglected. MRI and scintigraphy, performed in case of a high index of suspicion, are much more sensitive and allow an earlier diagnosis than plain radiography in chronic lesions.

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